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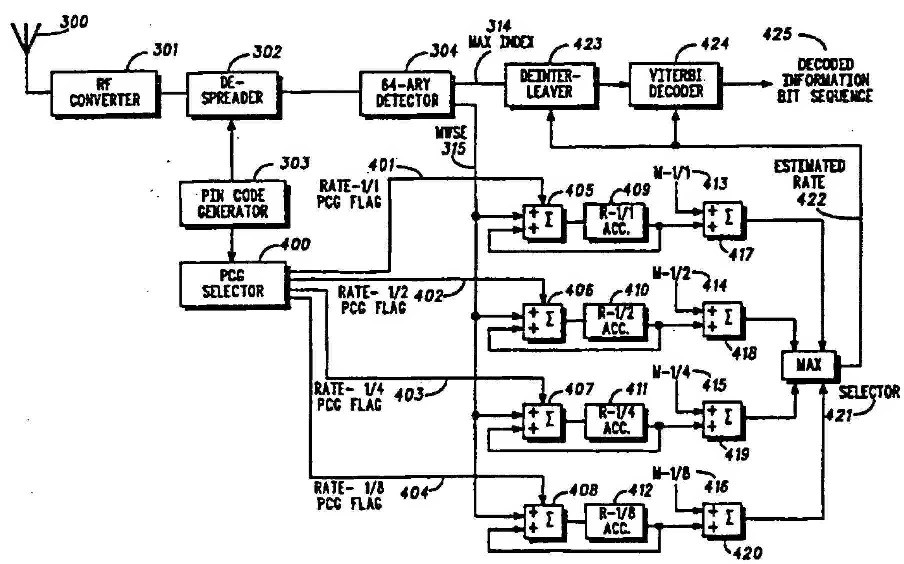
(54) Title: APPARATUS AND METHOD FOR RATE DETERMINATION IN ON-OFF VARIABLE-RATE COMMUNICATION SYSTEMS



(57) Abstract

Communication rate in a variable rate communication system is determined by calculating metrics based upon symbol energy over a traffic channel frame (200) and selecting an optimum rate based upon the calculated metrics. The metrics are calculated by selectively accumulating symbol energy, using adders (405-408) and accumulators (409-412) in response to the presence of power control groups (201) within the traffic channel frame (200), as determined by power control group selector (400).

APPARATUS AND METHOD FOR RATE DETERMINATION IN ON-OFF VARIABLE-RATE COMMUNICATION SYSTEMS

Field of the Invention

The present invention relates to rate determination in variable rate communications systems, and more particularly, to rate determination in communications systems in which on-off or amplitude-modulated keying is used to implement the variable-rate transmission scheme.

Background of the Invention

Making efficient use limited resources has long been an important goal of communication system designers. For example, in point-to-point communications systems – such as telephone modems – this usually means maximizing the rate of information transmission (in terms of bits of information per second) given limited transmitter power and channel bandwidth. In multiple access systems, such as cellular radio networks, the available resources are shared among many users and the goal of the system designer becomes that of maximizing the capacity of the system. This is often expressed in terms of the number of users that the system can simultaneously support at a specific information transmission rate per user.

In multiple access systems that support voice transmission the nature of the voice activity of each user can be exploited to further improve the efficiency of the communications system. For example, the well-known method of Digital Speech Interpolation (summarized in *Advanced Digital Communications*, by K. Feher) has long been used to increase the capacity of trunked telephone systems by digitally encoding and packetizing the speech of each of N users, and then multiplexing the resulting packet streams onto a single communications channel. Although there is a finite probability that

some packets will be erased, the effective capacity of the link is increased.

Related examples occur in cellular radio systems such as the Groupe Special Mobile (GSM) system specification issued by the European Telecommunications Standards Institute (ETSI). In this instance, a voice activity detector in the digital speech encoder used to encode each user's voice disables the user's transmitter when he or she is not speaking. Known as "Discontinuous Transmission" or "DTX", this technique offers the important benefit of reduced mobile station battery consumption, and nominally permits smaller radio frequency (RF) channel reuse distances (since the mean co-channel interference power is reduced), thereby increasing system capacity.

A similar technique is employed in the cellular communications system described by the North American Telecommunications Industry Association (TIA) Standard IS-95-A *Mobile Station–Base Station Compatibility Standard for Dual-Mode Wideband Spread Spectrum Cellular System*. This system specifies an air interface based on Code Division Multiple Access (CDMA). Since the capacity of such systems is limited by mutual interference between users, the system seeks to minimize the power transmitted by each user by exploiting voice activity.

TIA Standard IS-95-A describes different techniques for achieving this on each of the forward link (base station to mobile station) and the reverse link (mobile station to base station), but only the method used on reverse link is relevant to this discussion. As shown in Fig. 1 (an extended summary of TIA Standard IS-95-A Fig. 6.1.3.1-2), the mobile station (MS) partitions the 8kHz pulse code modulated (PCM) user voice signal (100) into 20ms segments or frames and then encodes those frames into information packets using a digital speech encoder (101). The exact specification of the digital speech

encoder (101) appears in TIA Standard IS-96-A *Speech Service Option Standard for Wideband Spread Spectrum Digital Cellular System.*

During encoding, each frame is classified by a voice activity detector (107) associated with the digital speech encoder (101) as belonging to one of four distinct transmission rates. These are labeled here as "rate-1/1", "rate-1/2", "rate-1/4", and "rate-1/8". Again, a precise description of the voice activity detector (107) appears in TIA Standard IS-96-A. It is sufficient to state that the speech encoder (101) uses more information bits to encode frames which occur during active talk spurts, and fewer bits during silence periods. Rate-1/1 uses most information bits while rate-1/8 uses fewest. Bit usage for frames encoded at rates-1/2 and -1/4 – which generally occur during transitions between active talk spurts and silence periods – lie somewhere between these limits.

The result of the frame classification process is indicated to the digital speech encoder (101) by the rate indicator (108) generated by the voice activity detector (107). The rate-1/1 and rate-1/2 packets are then subject to block or cyclic coding (102) as specified in TIA Standard IS-95-A section 6.1.3.3.2.1 *Reverse Traffic Channel Frame Quality Indicator.* This is followed by channel coding (103), which is specified as a rate-1/3 convolutional code in TIA Standard IS-95-A section 6.1.3.1.3 *Convolutional Encoding*. At this point, the number of channel-encoded bits forming an encoded packet (104) is listed in Table 1.

Selected Rate	Number of Encoded Bits in Packet
Rate-1/1	576
Rate-1/2	288

Rate-1/4	144
Rate-1/8	72

Table 1. Number of Encoded Bits per Packet by Rate

After interleaving (105) (specified by TIA Standard IS-95-A section 6.1.3.1.5 *Block Interleaving*), each encoded packet is further prepared for transmission by using 64-ary orthogonal modulation followed by direct sequence spreading using a 1.2288Mc/s user-specific pseudo-noise (PN) code (105) (see TIA Standard IS-95-A sections 6.1.3.1.6 *Orthogonal Modulation* and 6.1.3.1.9 *Quadrature Spreading*). For the purposes of this discussion, only the following details of this process are required. From Table 1, since the modulation scheme is 64-ary orthogonal, 96 symbols (commonly referred to as Walsh symbols) are required to transmit rate-1/1 packets. Likewise, 48 symbols are required for rate-1/2 transmission, 24 symbols are required for rate-1/4 transmission, and 12 symbols are required for rate-1/8 transmission. TIA Standard IS-95-A specifies that the symbols be transmitted in bursts of 6 consecutive Walsh symbols. In support of this, the TIA Standard IS-95-A sub-divides each 20ms traffic channel frame into 16 groups, known as "Power Control Groups" (PCG's), each capable of transmitting a single group of 6 Walsh symbols (see TIA Standard IS-95-A section 6.1.3.1.7 *Variable Data Rate Transmission*). Depending on the selected rate therefore, the number of PCG's during which the MS is actively transmitting may therefore total 16, 8, 4, or 2 for rates-1/1 through 1/8 respectively. Note that MS transmitter is disabled during inactive PCG's.

This process is illustrated in more detail in Fig. 2, which shows transmitter activity during a 20ms traffic channel frame (200) for each of the possible packet sizes or rates. In Fig. 2, shading of a PCG interval (201) implies that a burst of 6 direct sequence spread Walsh symbols was transmitted during that PCG. Thus, if the selected packet rate is

rate-1/1, all 16 PCG's in a 20ms traffic channel frame will be active as shown by case (202) of Fig. 2. If the selected packet rate is rate-1/2, the MS transmitter will be active during only 8 PCG's as shown by case (203). Likewise, a rate-1/4 packet will generate the active PCG's shown in case (204), while the rate-1/8 case is shown as case (205).

Note that for rates 1/2, 1/4, and 1/8 (sometimes referred to collectively as the "sub-rates"), the PCG's which are active in any given 20ms frame are determined from a pseudo-random PCG selection procedure driven by observations of the user-specific PN code during the traffic channel frame preceding the frame under analysis as described in TIA Standard IS-95-A section 6.1.3.1.7.2 *Data Burst Randomizing Algorithm*. Specifically, the last 14 bits of the user-specific PN code generated during the next to last PCG of the previous frame are stored, and used to select the PCG's that will be active, for each transmission rate, in the following frame. Since the user-specific code has a repetition interval of several days, and is shifted for each user, the position of the active PCG's in any particular traffic channel frame therefore depends on the time at which the frame is transmitted, the identity of the user, and the rate of the packet transmitted during that frame. Of course, the number of active PCG's remains unchanged for each rate – only the position of the active PCG's change pseudo-randomly with time and user identity.

It is important to realize that – in order to perform de-spreading – the base station (BS) receiver must re-generate the user-specific PN code used at the MS to perform direct sequence spreading. Accordingly, the BS receiver can also unambiguously identify the PCG's used to transmit a packet at any of the four possible rates. Further, since the PCG selection procedure depends only on the user-specific PN code sequence observed during the previous frame, the BS receiver can identify the active PCG's for the current frame *at the start* of the current frame.

By using this method of variable-rate transmission, TIA Standard IS-95-A mobile stations are able to reduce battery consumption, and the average amount of interfering power presented to other IS-95-A mobile stations using the same carrier frequency. Note, however, that neither the digital speech encoder (101) defined in TIA Standard IS-96-A nor the traffic channel physical layer structure defined in TIA Standard IS-95-A provides side-information to indicate to the base station receiver which of the four rates were selected for transmission of a given packet. Thus the base station receiver is required to *estimate* the rate of transmission – process sometimes referred to as "rate determination".

Prior methods of performing rate determination include the technique implemented in the *Base Station Modem* (BSM) chipset manufactured by Qualcomm Inc, of San Diego, CA for use in TIA Standard IS-95-A compliant base station receivers. A simplified block diagram of this approach is shown in Fig. 3.

The procedure begins by first converting (300,301) the received radio frequency (RF) waveform comprising each direct sequence spread Walsh symbol from an RF signal to a baseband signal sampled at the chip rate. This requires various well-understood RF, intermediate frequency (IF), and baseband functions such as frequency conversion, automatic gain control, symbol sampling etc., but these need not be specified here in detail. Each transmitted Walsh symbol waveform is then recovered, after being corrupted by noise and distorted by the communication channel, by despreading (302) which requires correlation with the user-specific PN sequence (303) used to spread the transmitted Walsh symbols. Walsh symbol detection is then performed (304) using the well-known method of correlating the received Walsh symbol waveform against the set of 64 waveforms comprising the symbol alphabet in a 64-ary correlator (312). The

precise details of this technique and its performance are very well known and are described in standard texts on digital communications, including *Digital Communications* by J.G. Proakis. The maximum likelihood method of identifying the transmitted Walsh symbol when no received signal phase reference is available (i.e. under "noncoherent" conditions) is to select that correlator and corresponding symbol index which maximizes the magnitude of the complex-valued cross-correlation between the 64 possible symbol waveforms and the received waveform. This selection process is performed in the block marked 'Max' (313) in Fig. 3. The *magnitude-square* value of that maximum magnitude cross-correlation result is referred to here as the "maximum Walsh symbol energy" or MWSE and is shown being generated as output (315).

The index (314) corresponding to the correlator which gave the maximum magnitude correlator output is then passed to the block deinterleaver (305) where the channel symbols comprising each Walsh symbol are deinterleaved and convolutionally decoded (306) using the well-known Viterbi algorithm. The deinterleaving and Viterbi decoding processes (305) and (306) are performed four times – once under the hypothesis that each possible packet transmission rate was used. During Viterbi decoding (306), an estimate of the number of channel symbol errors present in the received packet is computed for each of the four possible rates by the well-known method of comparing the received channel encoded symbols with those obtained by convolutionally re-encoding the Viterbi decoder output for each rate. A 4-ary vector (308) containing the estimated number of symbol errors by rate is then passed to the rate determination function (309). Finally, the block or cyclic codes associated with rate-1/1 and rate-1/2 packets (referred to in TIA Standard IS-95-A as the Frame Quality Indicators) are decoded (307) and their syndromes or checksums (as defined in *Error Control Coding* by S. Lin, and D.J. Costello) made available to the rate determination function (309) as a 2-ary vector (310).

Rate determination is then performed by partitioning the 6-ary decision space formed by the 4-ary symbol error count and 2-ary checksum vectors (309) and (310), and then estimating the transmitted rate by identifying the region of the decision space in which the 6-ary vector corresponding to the received packet lies. If the rate of the transmitted packet cannot be confidently established (i.e. it lies outside the decision regions of all four rates), the packet may be declared "erased". No further processing, such as speech decoding, is performed on such packets.

This approach suffers the disadvantage of requiring four distinct Viterbi decoding operations (one for each transmitted rate hypothesis). This is computationally expensive and inefficient in terms of power consumption. Further, the audio delay resulting from the need to perform multiple Viterbi decodes before the determined rate can be passed to the speech decoder can reduce perceptual audio quality. Therefore a need exists for an apparatus and method for rate determination in variable rate communication systems which is computation and power efficient and which does not degrade perceptual audio quality.

Brief Description of the Drawings

FIG. 1 shows generally a prior art method of performing speech and channel coding, and modulation and direct sequence spreading of the reverse link traffic channel frame in a communication system having a variable-rate speech service option.

FIG. 2 shows an example of the prior art power control group (PCG) structure of a particular frame of the reverse link traffic channel frame when the variable-rate speech service option is in use.

FIG. 3 shows a prior art method of rate determination for the reverse link traffic channel packets.

FIG 4 is a block diagram illustrating a preferred implementation of a rate determination apparatus in accordance with the present invention.

FIG. 5 is a block diagram illustrating an alternate preferred implementation of a rate determination apparatus in accordance with the present invention.

Detailed Description of a Preferred Embodiment

A block diagram of a preferred embodiment of an apparatus for rate determination appears in Fig. 4. Fig. 4 shows the process of RF conversion (300,301) and despreading (302) used to recover the noisy orthogonal waveform corresponding to each transmitted Walsh symbol comprising a traffic channel frame. Also shown is the user-specific PN code generator (303) used to generate the despreading sequence, and the Walsh symbol detector (304) comprising the 64-ary correlator (312) and selector function (313). The Walsh symbol detector is shown generating the maximum Walsh symbol energy (MWSE) value (315).

The MWSE for each received Walsh symbol is then passed to four accumulators (409–412), labeled in abbreviated fashion "R-1/1 Acc." (409) through "R-1/8 Acc." (412) for "rate-1/1 accumulator" (409), etc. The contents of these accumulators are uniformly set to zero at the start of each traffic channel frame. The adders (405-408) associated with each accumulator are gated by control signals from the PCG selector function (400), and only accumulate the MWSE when the corresponding PCG flag has logical value '1'. The PCG selector function (400) observes the output of the user-specific PN code generator over the previous traffic channel frame and identifies, according to the method defined by TIA Standard IS-95-A section 6.1.3.1.7.2 *Data Burst Randomizing Algorithm*, the PCG's which would be active in the

current traffic channel frame for each possible transmitted rate. The PCG selector (400) outputs 4 binary flags (401-404) labeled "rate-1/1 PCG flag" through "rate-1/8 PCG flag". These flags are logically '1' if and only if the Walsh symbol being demodulated by the detector (304) is a member of an active PCG for the rate associated with that flag. In other words, and referring to the example of Fig. 2, the rate-1/2 PCG flag is logically '1' only during the shaded portions of the traffic channel frame corresponding to case (203). Similarly, the rate-1/4 PCG flag only has value '1' during the shaded periods of case (204), and so on. This process continues until all 96 Walsh symbols comprising a frame have been received. At the end of the frame, therefore, the accumulator labeled "R-1/1 Acc." has accumulated 96 MWSE values, the "R-1/2 Acc." has accumulated 48 MWSE values, the "R-1/4 Acc." has accumulated 24 MWSE values, and "R-1/8 Acc." has accumulated 12 MWSE values.

After the entire frame has been received, the contents of accumulators (409-412) are fed to subtractors (417-420). A scalar value, which is generally different for each accumulator, and which is labeled M-1/1 through M-1/8 (413-416) in Fig. 4, is then subtracted from each accumulator (409-412) output. The resulting output of each subtractor (417-420) is then fed to a selector (421) which identifies the maximum of the four subtractor (417-420) outputs. This uniquely identifies which of the accumulators (409-412) led to the maximum value at the selector (421). The estimated transmission rate (422) is then identified as that corresponding to the accumulator (409-412) which produced that maximum value at the selector (421). The estimated rate (422) is used to control operation of the deinterleaver (423) and Viterbi decoder (424). These devices execute only once to decode the received channel symbols according to the rate predicted by the estimated rate (422).

Note that the scalar values M-1/1 through M-1/8 (413-416) are established beforehand by computer simulation or by bench testing.

They are, in-practice, generally constant throughout the duration of the traffic channel frame under analysis. They may, however, change in value at each Walsh symbol boundary, depending on other parameters associated with the base station receiver. One specific example of this arises from the use of a "rake" receiver to exploit the presence of multipath signal components in the communications channel. [Rake receivers are well known in the art and need not be described here.]

This is shown in Fig. 5 for the case of a 4-element rake receiver, where each element (500) comprises at least a despreader (302) and 64-ary correlator (312). Note that more or less elements (500) than 4 may be used depending on the application. In Fig. 5, each element is assigned to a distinct multipath signal component, with differences in the observed delay of each multipath signal component compensated by the delay elements Δ_1-Δ_4. (502-505). Each despread multipath signal component is then passed through a 64-ary correlator (312) of the same type as that described above. A 64-ary vector is then formed at the output of each correlator (312), where the i-th element of the 64-ary vector is the magnitude-square of the i-th correlator output. This leads to a classical non-coherent combining method which is referred to as "square-law" combining in standard texts such as *Digital Communications* by J.G. Proakis. In Fig. 5, 4 such vectors are combined (522) by simple vector addition. The maximum Walsh symbol energy (MWSE) (315) is then identified (523) as the maximum-valued element of the resulting combined 64-ary vector, with the MWSE (315) subsequently used for rate-determination in the manner shown in Fig. 4.

The relative strength of each multipath component may vary, however, with time. Accordingly, the number of elements (500) that are operating on multipath components which contribute significantly to the vector combining process (522) may change. Provided the RF

converter (301) incorporates an automatic gain control stage, the relative contribution of each element (500) can be estimated using a simple signal-noise ratio (SNR) estimator (501) such as that shown in Fig. 5. This SNR estimator operates by comparing the MWSE (506-509) of the individual 64-ary vectors at the output of each element's correlator (312) to a threshold T (510). If the MWSE (506-509) of a particular element exceeds T (510), the corresponding 64-ary vector at the 64-ary correlator output of that element is included in the combining process (522), else it is excluded. When an element is declared included in the combining process, it is referred to as being "in-lock". An in-lock indicator for each element is shown in Fig. 5 as the binary lock flags L1-L4 (515-518). Also shown is a counter (519) which accumulates the number of elements currently in-lock by observing L1-L4 (515-518). This count (520) is used to obtain the row address of a 4x4 lookup table (521). The columns of the table contain the values of M-1/1 (413) through M-1/8 (416) to be used according to the number of element in lock. The contents of the lookup table are established beforehand by computer simulation or by bench testing.

Clearly, the estimated rate (430) need not be exclusively determined from the metrics available at output of subtractors (417-420) in Fig. 4. Instead these metrics could be used as supplementary information for rate determination based upon, for example, symbol error rate or path metric information derived from the Viterbi decoder. It is also clear that the technique may readily be extended to estimate the rate of a variable-rate transmission derived from a information source other than speech. This might include variable-rate data transmission.

Thus it is readily appreciated that the present invention provides a power and computation efficient apparatus and method for rate determination which does not negatively impact perceptual audio quality. In addition, further advantages and modifications will readily

occur to those skilled in the art. The invention, in its broader aspects, is therefore not limited to the specific details, representative apparatus, and illustrative examples shown and described herein. Various modification and variation can be made to the above specification without varying from the scope or spirit of the invention, and it is intended that the present invention cover all such modifications and variations provided they come within the scope of the following claims and their equivalents.

Claims

What we claim is:

1. A method of rate determination in a variable rate communication system comprising the steps of:

computing a metric based on symbol energy for a data packet at each of a plurality of possible transmitted packet rates; and

selecting an optimum rate based upon the computed metrics.

2. The method of claim 1, wherein the step of computing a metric comprises computing a metric based on symbol energy depending on a number of elements of a rake receiver that are in use.

3. The method of claim 1 further comprising the step of computing at least one additional metric based on one of the following: convolutional decoder distance metric; Viterbi decoder metric, block coding metric; and

wherein the step of selecting further comprises selecting an optimum rate from the selected and the at least one additional metrics.

4. A method of rate determination in a variable rate information system comprising the steps of:

computing a plurality of metrics based on a summation of a symbol energy of a plurality of symbols comprising each of a plurality of transmitted symbol rates; and

selecting a rate associated with a maximum computed metric.

5. The method of claim 4 further comprising computing at least one additional metric based on one of the following: convolutional decoder distance metric; decoder metric, block coding metric; and

wherein the step of selecting further comprises selecting an optimum rate from the selected and the at least one additional metrics.

6. An apparatus for rate determination in a variable rate communication system comprising:

a plurality of accumulators selectively accumulating a maximum Walsh symbol energy over a traffic channel frame, each accumulator having an output; and

a selector coupled to the outputs of the accumulators for selecting an optimum rate based upon the outputs.

7. The apparatus of claim 6 further comprising a power control group flag generator coupled to each of the accumulators and wherein the accumulators selectively accumulate maximum Walsh symbol energy in response to the presence of a power control group flag.

8. The apparatus of claim 6 wherein the selector comprises a plurality of subtractors respectively coupled to the outputs of the plurality of accumulators for subtracting a scalar value from the outputs.

9. A method of rate determination in a variable rate communication system comprising the steps of:

accumulating a plurality of maximum Walsh symbol energy values over a traffic channel frame; and

selecting an optimum rate based upon the values.

10. The method of claim 9 wherein the step of accumulating a plurality of maximum Walsh symbol energy values comprises accumulating a plurality of maximum Walsh symbol energy values in response to power control groups with the traffic channel frame.

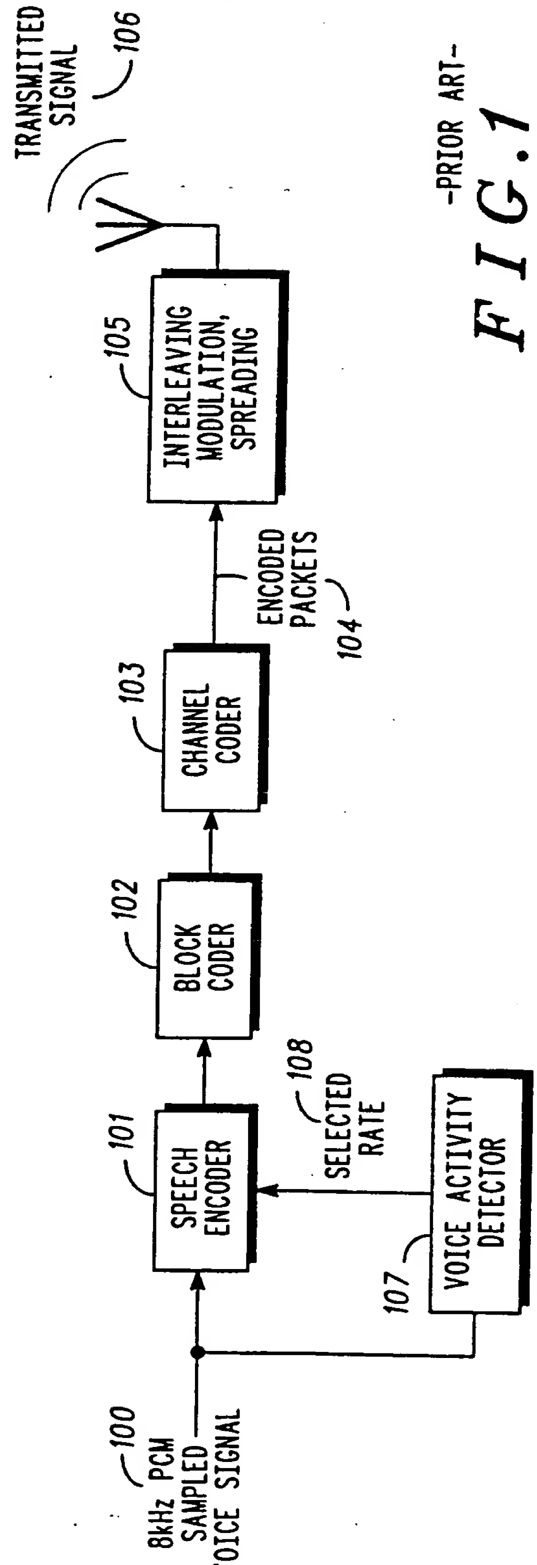


FIG.1
-PRIOR ART-

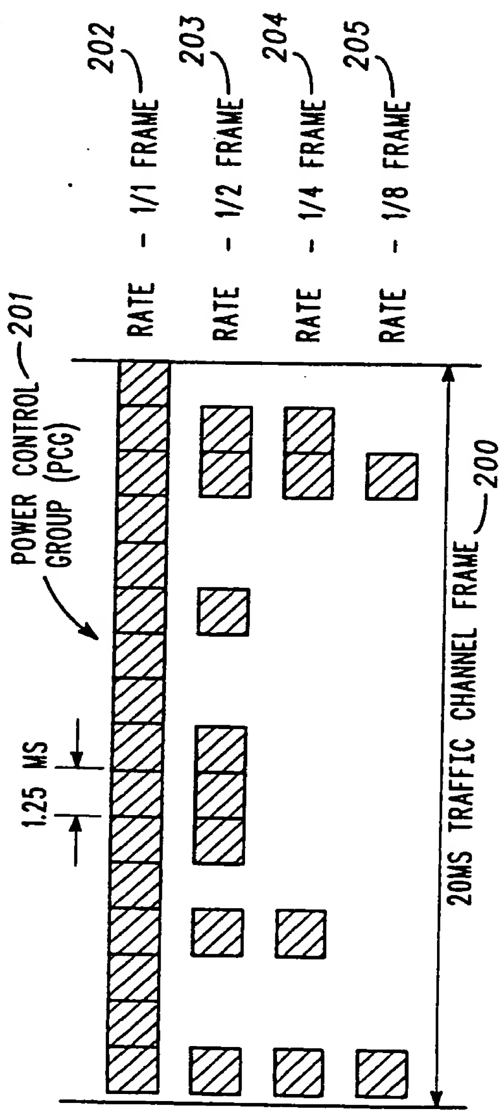
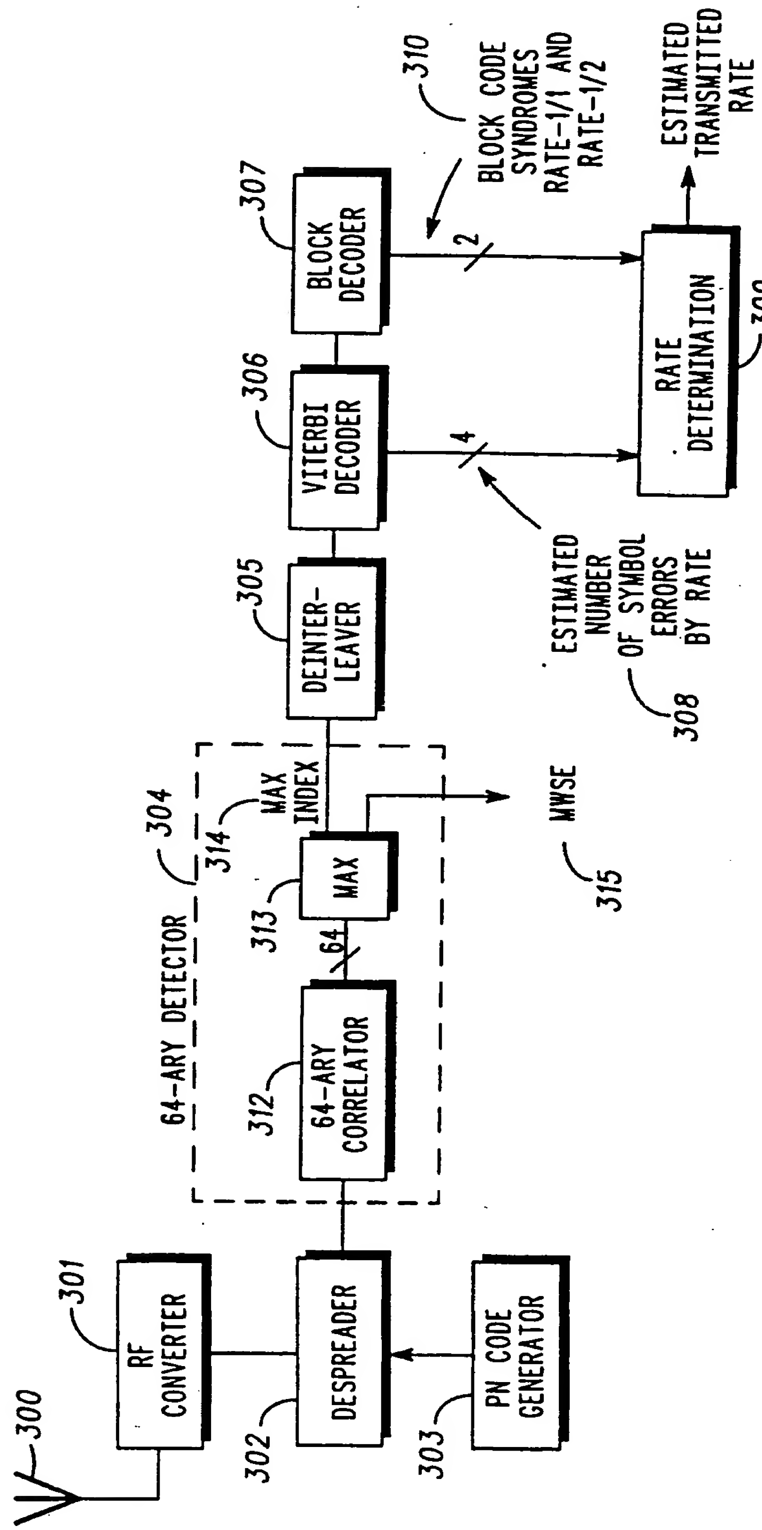
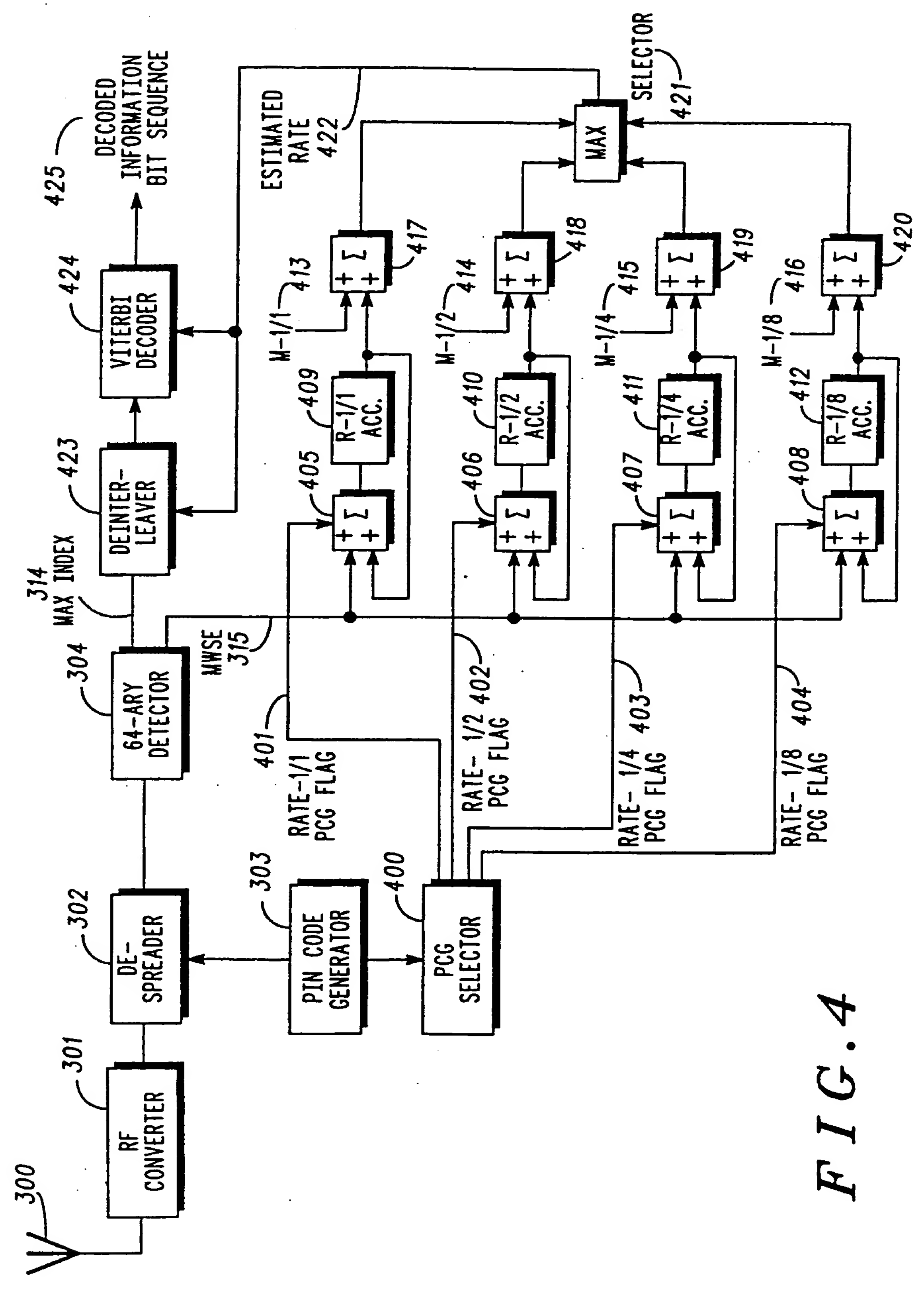


FIG.2
-PRIOR ART-



-PRIOR ART-

FIG. 3



300
301
RF CONVERTER
302
DE-SPREADER
303
PIN CODE GENERATOR
400
PCG SELECTOR
304
64-ARY DETECTOR
314
MAX INDEX
MWSE 315
423
DEINTER-LEAVER
424
VITERBI DECODER
425
DECODED INFORMATION BIT SEQUENCE
401
RATE-1/1 PCG FLAG
RATE- 1/2 PCG FLAG 402
RATE- 1/4 PCG FLAG 403
RATE- 1/8 PCG FLAG 404
405
406
407
408
409
R-1/1 ACC.
410
R-1/2 ACC.
411
R-1/4 ACC.
412
R-1/8 ACC.
M-1/1 413
M-1/2 414
M-1/4 415
M-1/8 416
417
418
419
420
MAX
SELECTOR 421
ESTIMATED RATE 422

FIG. 4

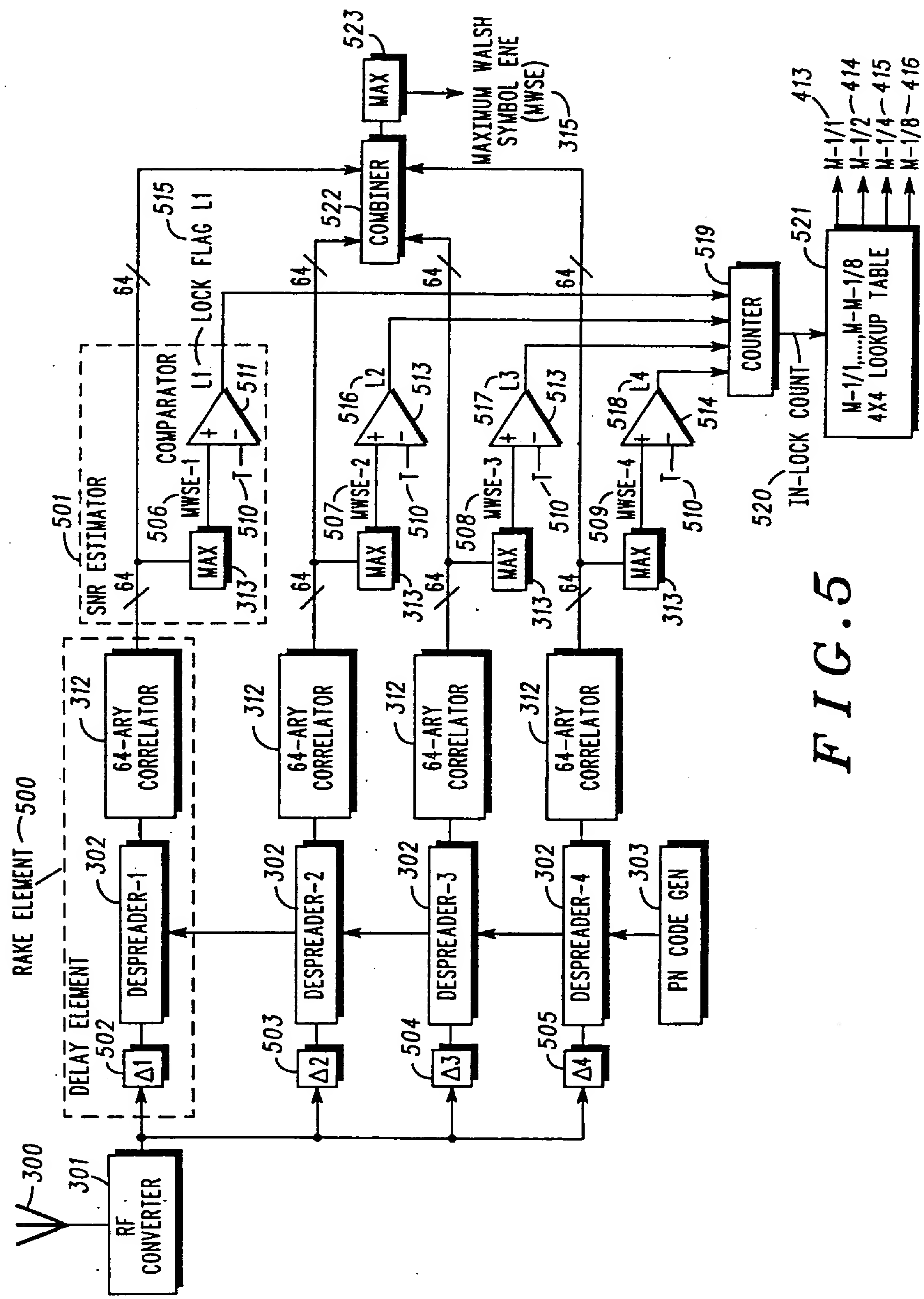

RF CONVERTER
300
301
RAKE ELEMENT
500
DELAY ELEMENT
502
503
504
505
Δ1
Δ2
Δ3
Δ4
DESPREADER-1
DESPREADER-2
DESPREADER-3
DESPREADER-4
302
PN CODE GEN
303
64-ARY CORRELATOR
312
64
SNR ESTIMATOR
501
MAX
313
MWSE-1
MWSE-2
MWSE-3
MWSE-4
506
507
508
509
COMPARATOR
T
510
511
513
514
516
517
518
L1
L2
L3
L4
LOCK FLAG L1
515
COMBINER
522
MAX
523
MAXIMUM WALSH SYMBOL ENE (MWSE)
315
COUNTER
519
IN-LOCK COUNT
520
M-1/1,...,M-M-1/8 4X4 LOOKUP TABLE
521
M-1/1
M-1/2
M-1/4
M-1/8
413
414
415
416

FIG. 5